NUMERICAL SIMULATIONS AND ACCELERATED CORROSION TESTS TO STUDY THE CRACK PATTERN OF REINFORCED CONCRETE SAMPLES

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Motivation

Main aspects of corrosion:

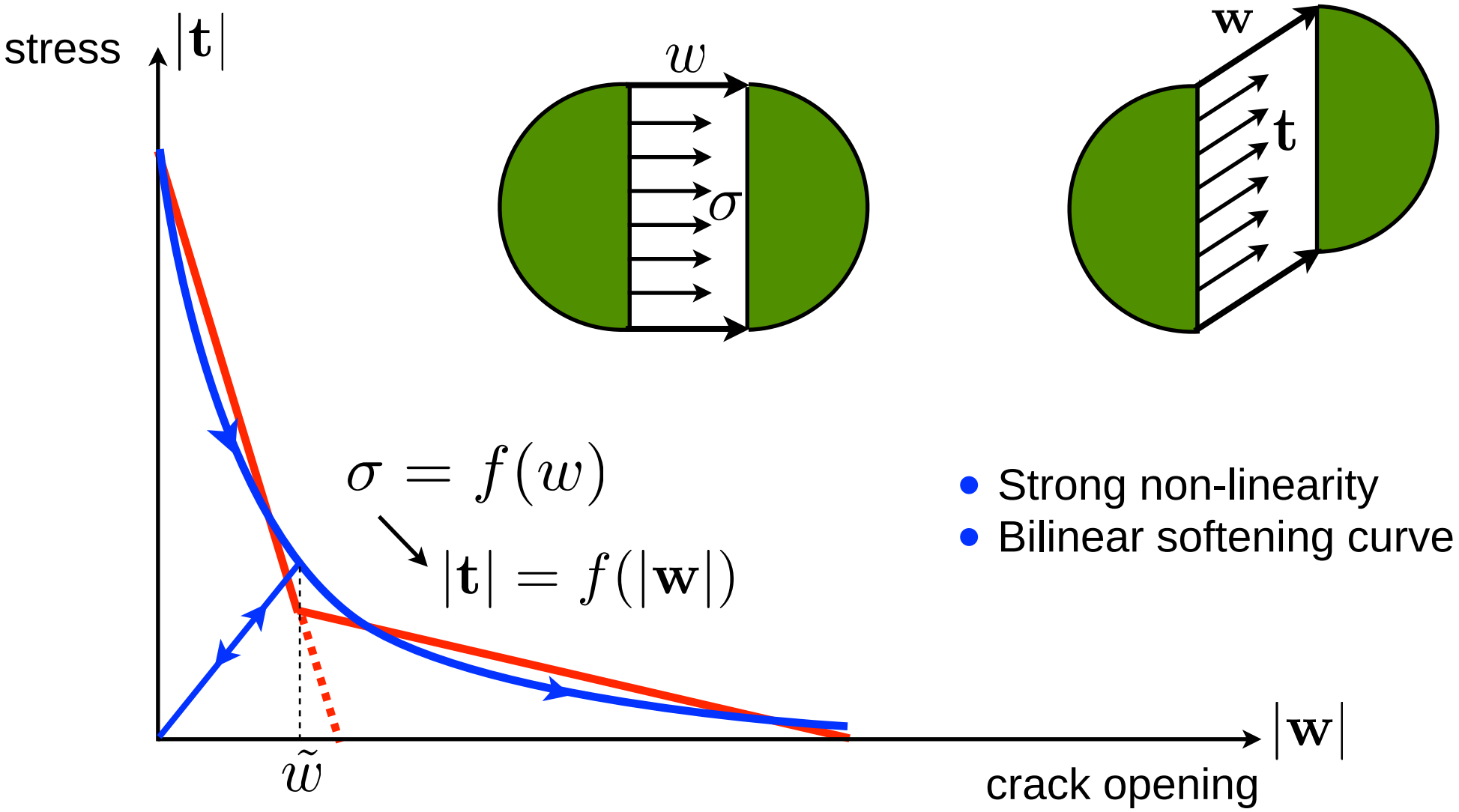
- Decrease in the net cross-sectional area
- Volumetric expansion of the oxide
- Cracking of the concrete cover and spalling

Objective:

- To predict the mechanical effects of the oxide over the concrete

1. Numerical model for the oxide
   - Expansive joint element
2. Accelerated corrosion tests

Concrete cracking: Standard cohesive model

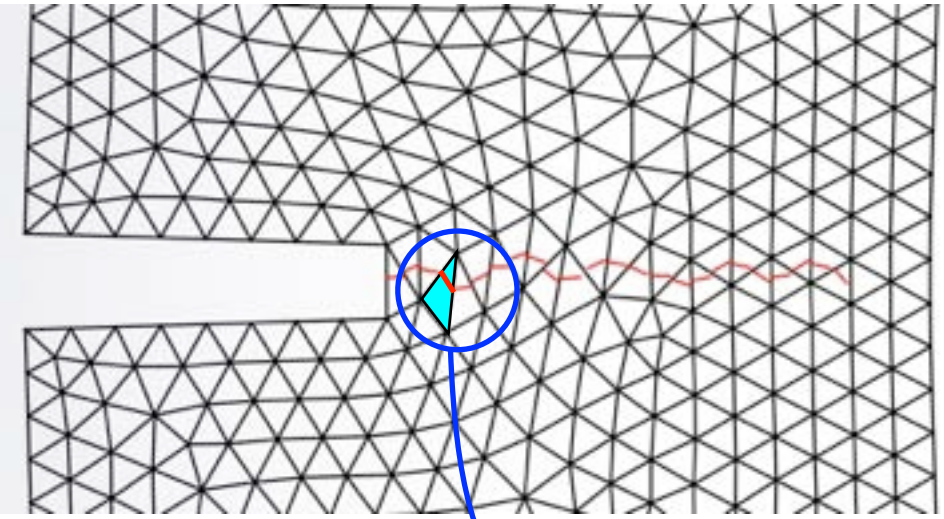


- Strong non-linearity
- Bilinear softening curve

$$\mathbf{t} = \frac{f(\tilde{w})}{\tilde{w}}\mathbf{w} \quad \text{with } \tilde{w} = \max(|\mathbf{w}|)$$

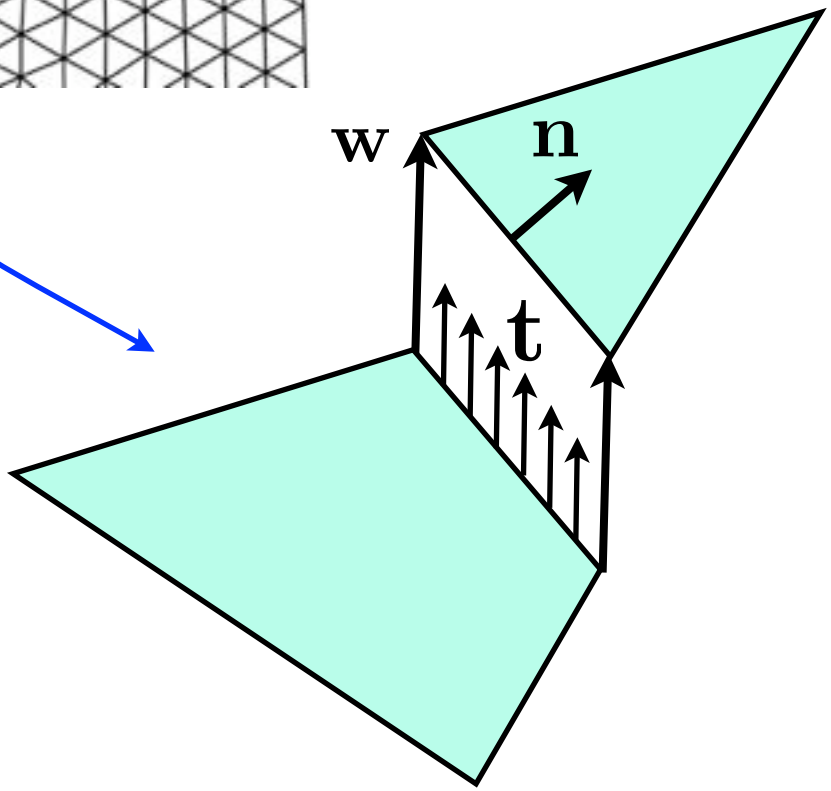
Finite element program: COFE (Sancho et al, 2003)

Continuum-Oriented Finite Elements



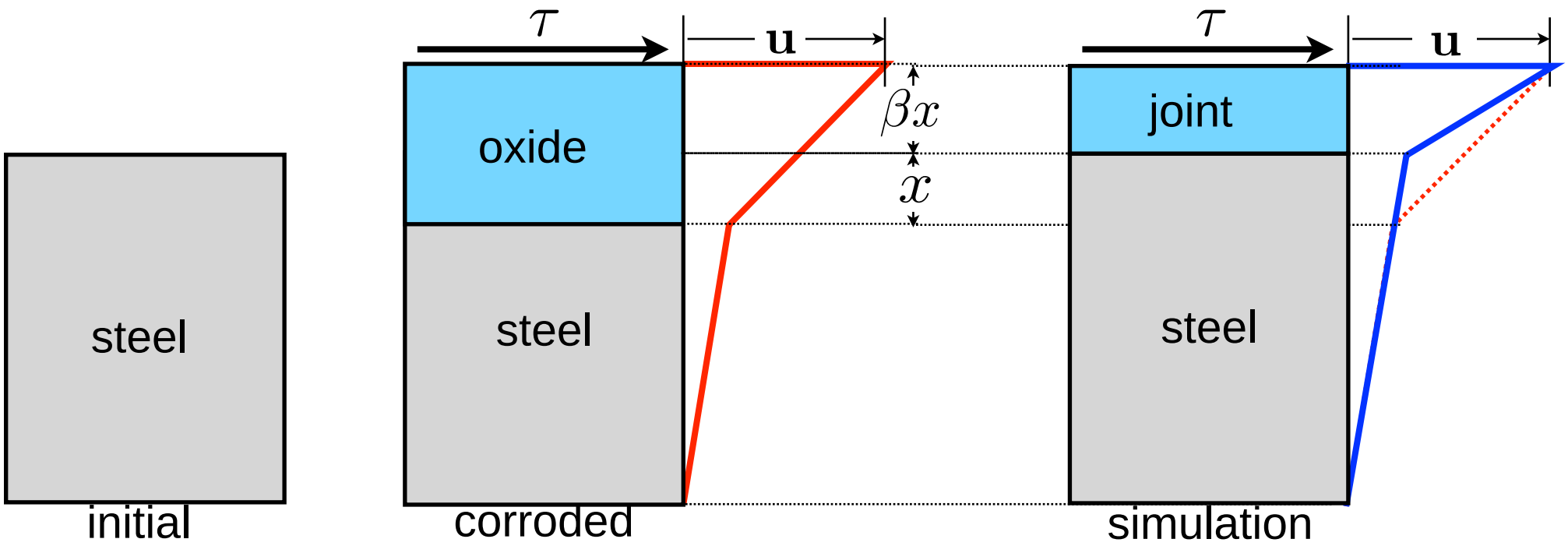
Adaptable embedded crack

- Strong discontinuity kinematics
- Constant strain elements
- Simple cohesive model
- Limited local crack adaptation



Oxide layer: Expansive joint element

- The oxide is already forming
- The corrosion depth is given at any specified time

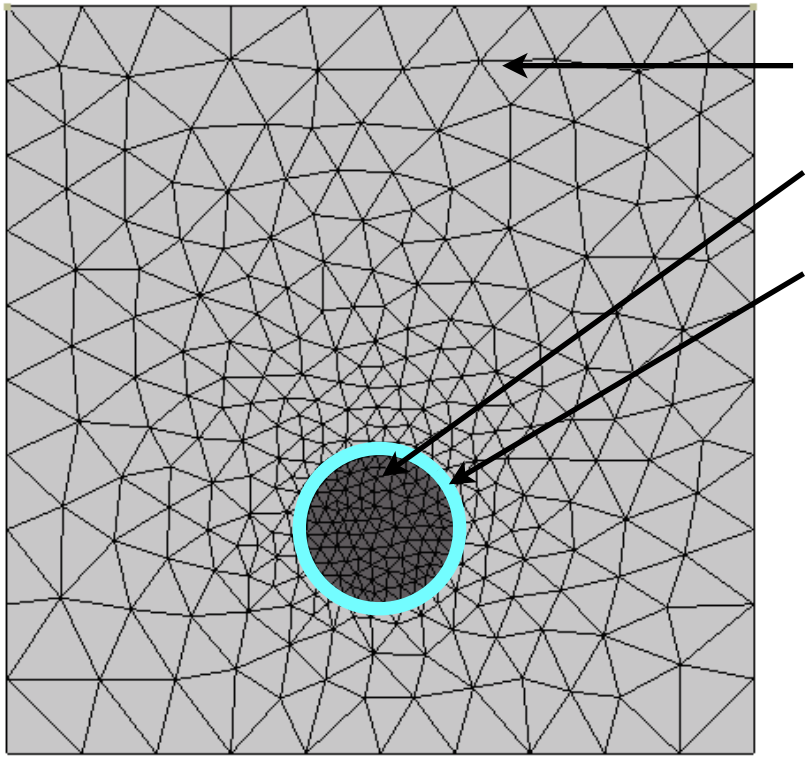


Mechanical equivalence oxide - element

Debonding ability

- *Nearly free sliding*: very small shear stiffness
- *Nearly free separation*: very small tensile stiffness

Parameters of the simulations



Concrete: cohesive embedded crack

Steel: linear elastic

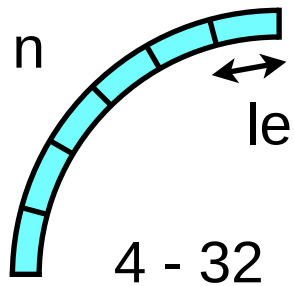
Oxide: expansive joint element

- GMSH (Geuzaine)
- Constant Strain Triangles

Corrosion

- Total diametral expansion: 50 μm
- 50 steps

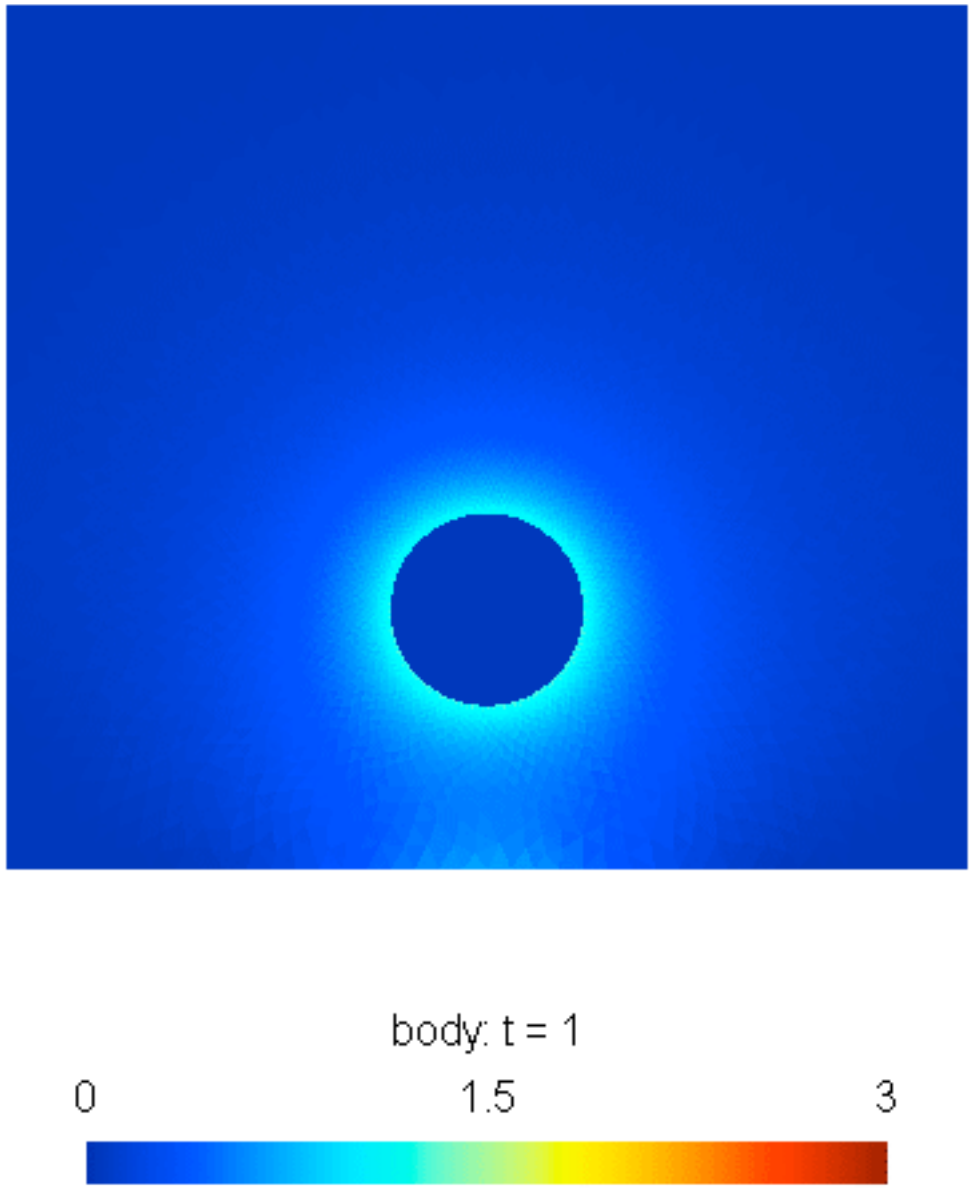
Size effect study



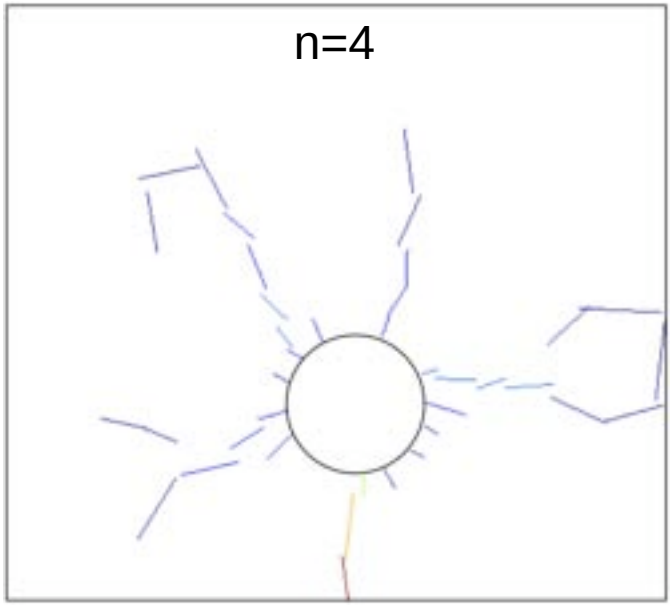
3.93 - 0.49 mm

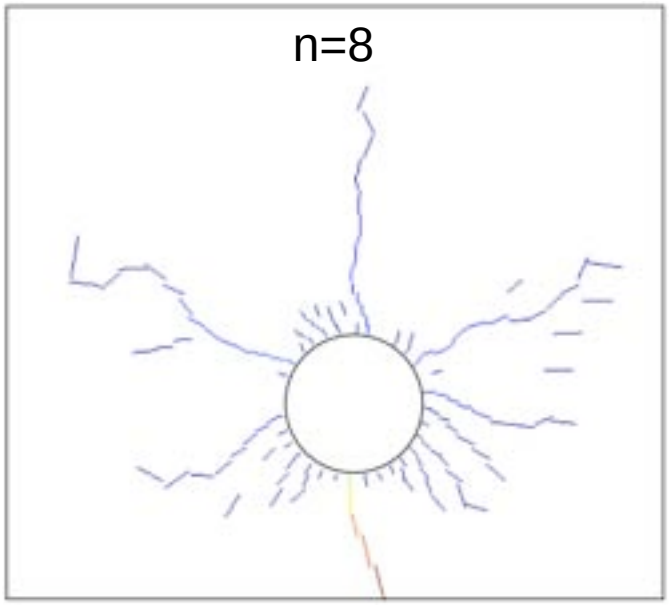
Simulations using the expansive joint element

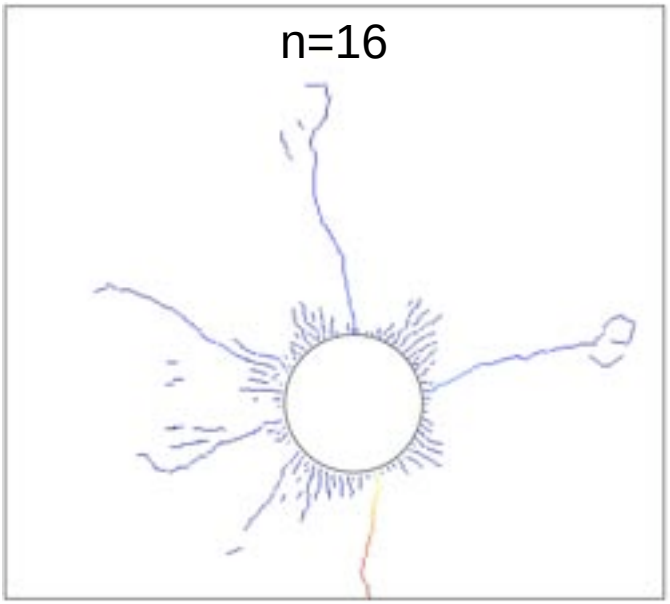
n = 32
(elem/quarter)

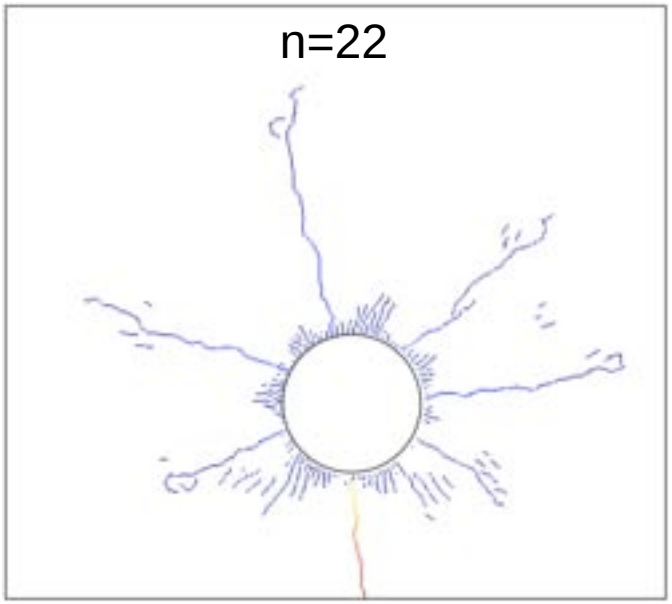


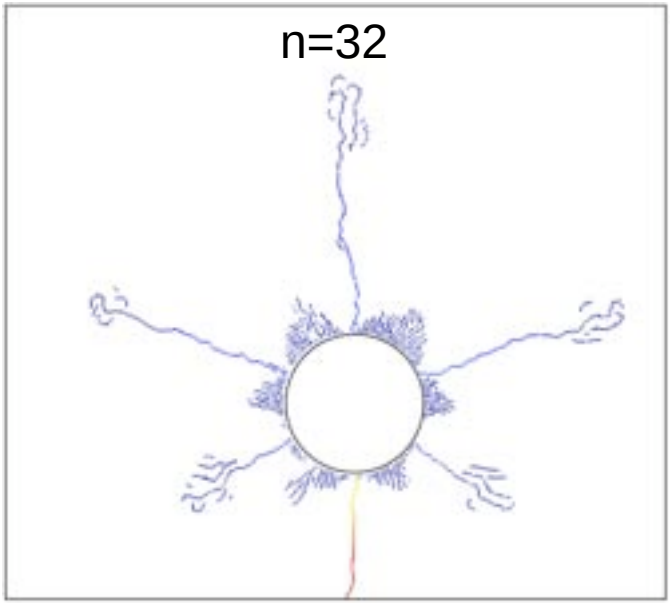
Size effect study in the simulations





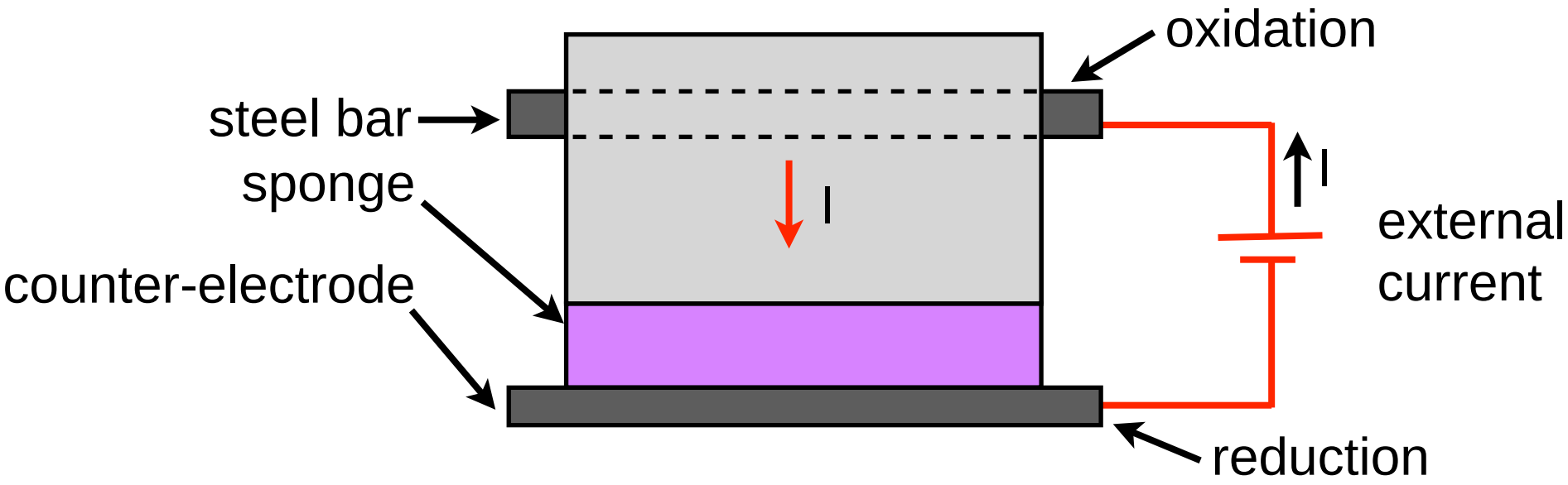


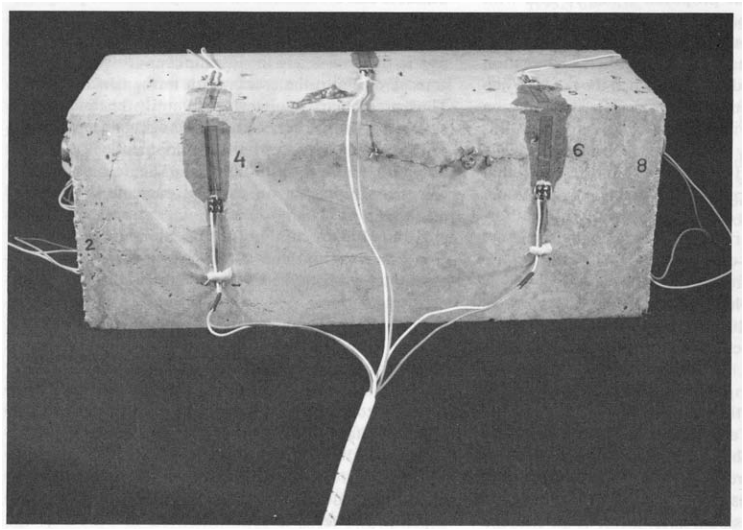


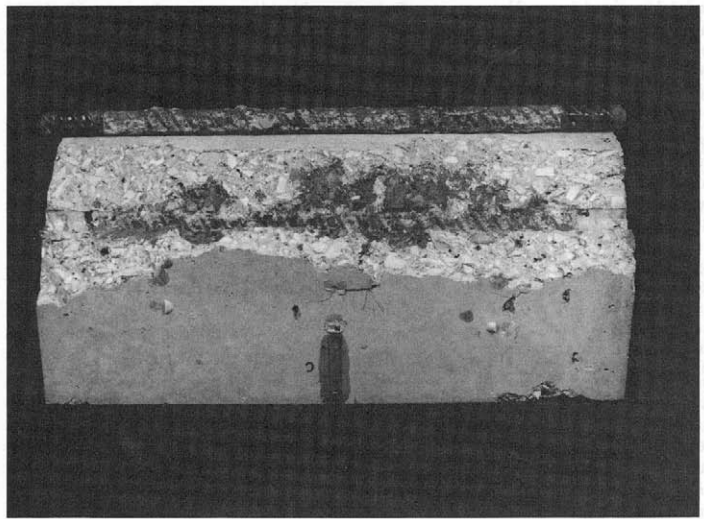


Previous models for accelerated corrosion tests

Andrade et al (1993)

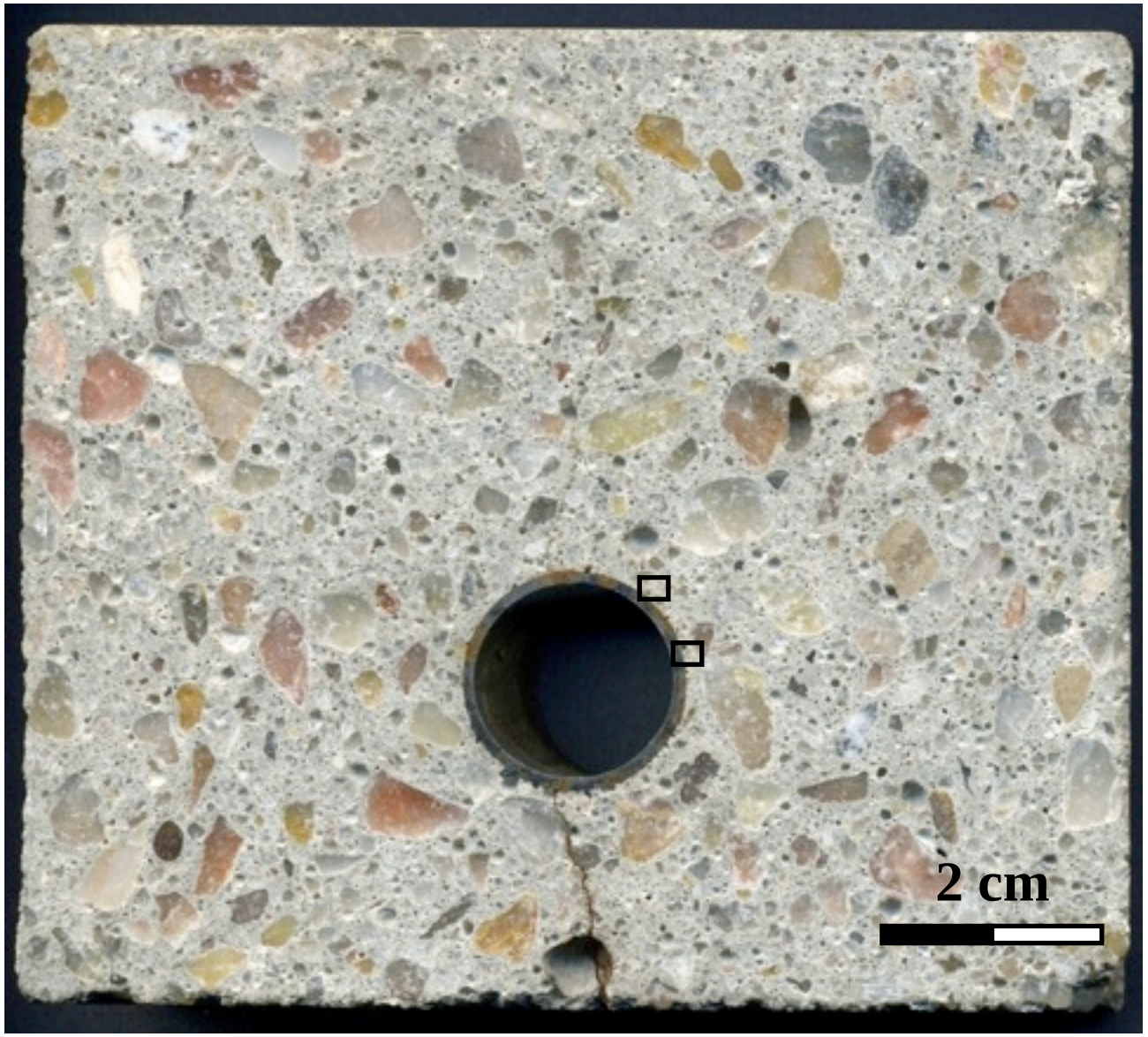


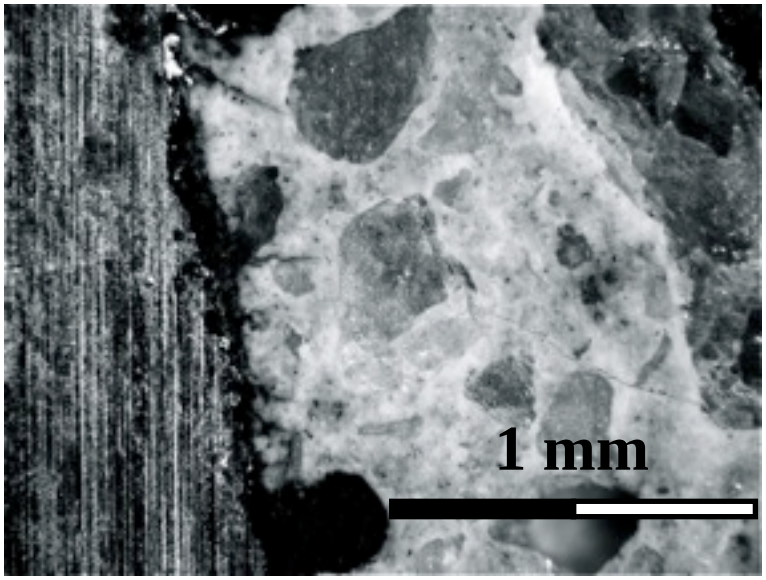


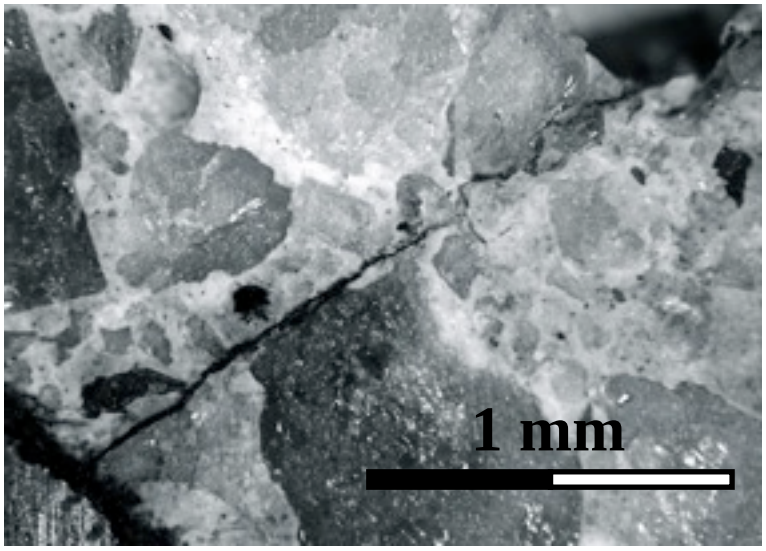


he concrete.

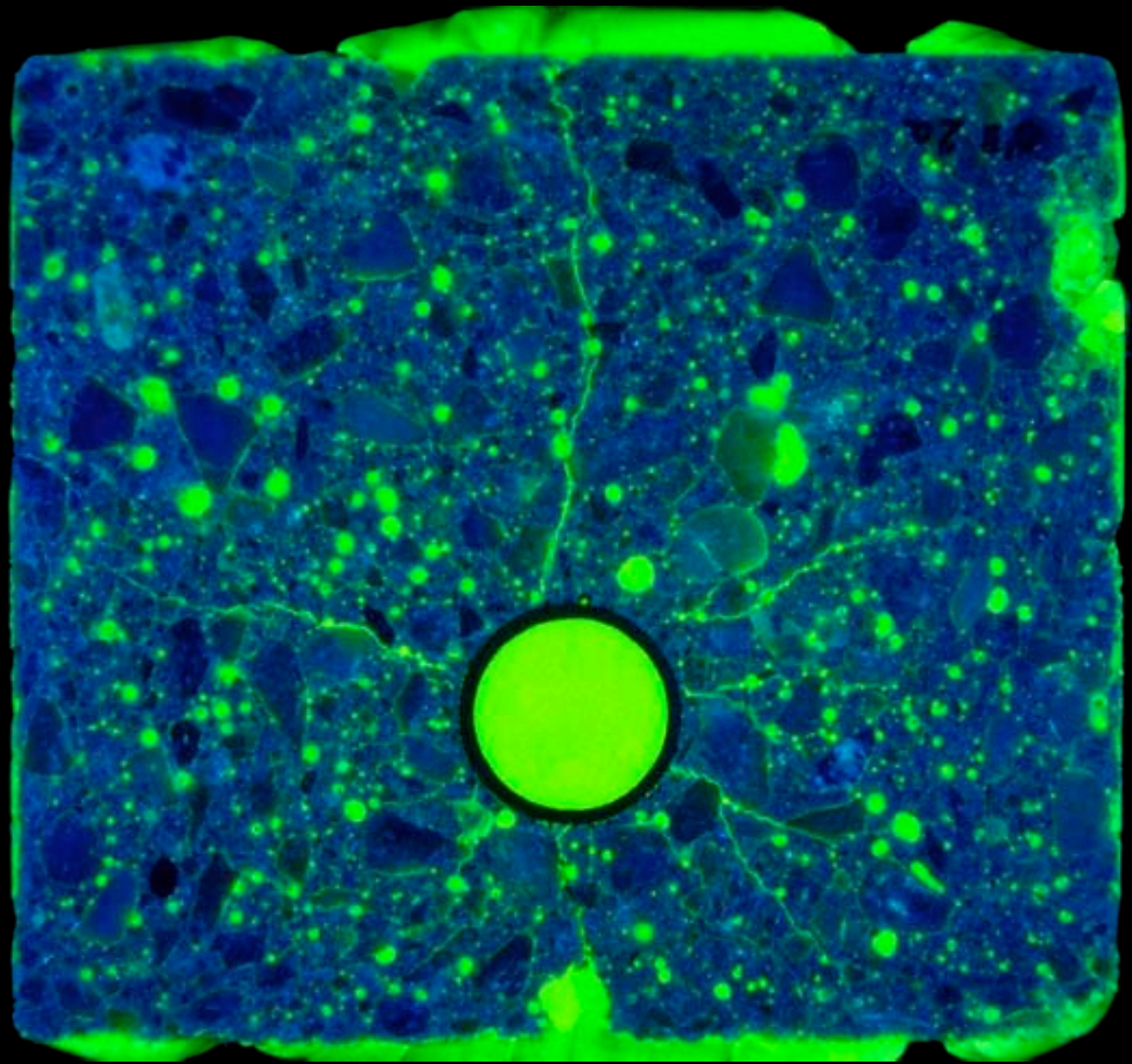
Crack pattern in accelerated corrosion tests







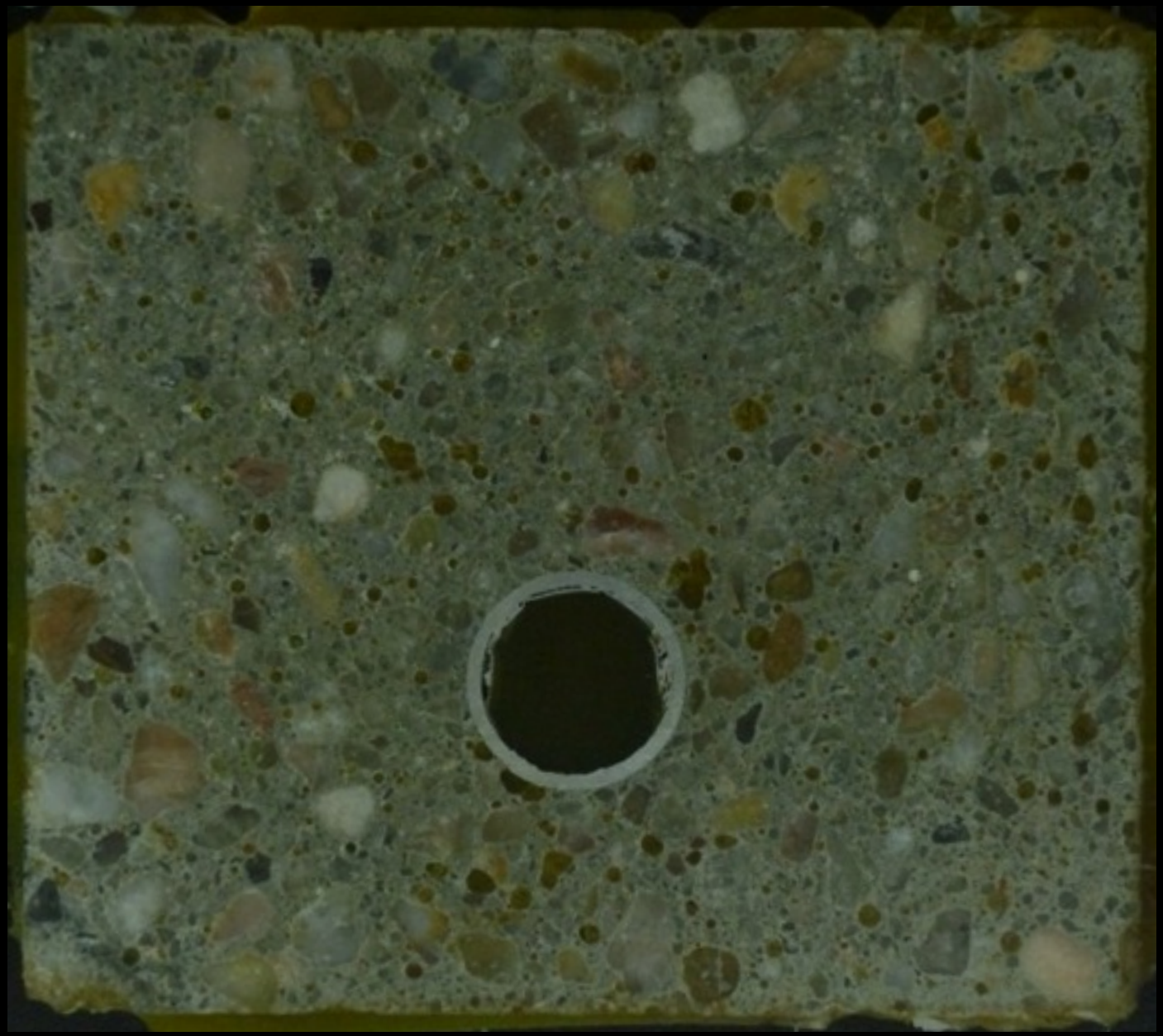
Crack pattern in accelerated corrosion tests



Crack pattern in accelerated corrosion tests

Crack pattern in accelerated corrosion tests

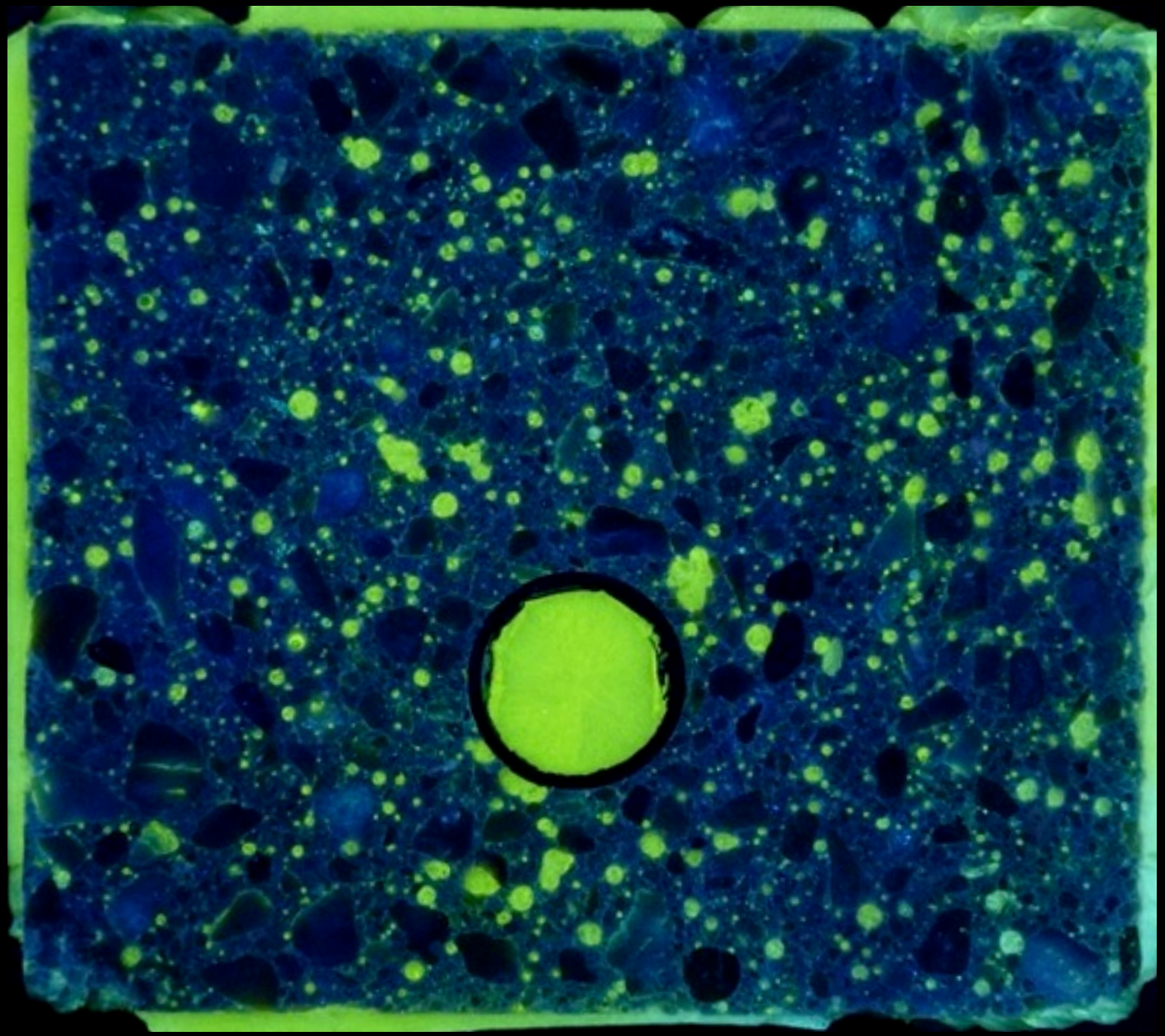
$\Delta\text{ø} = 0\ \mu m$



T03-05-R02

Crack pattern in accelerated corrosion tests

$\Delta\text{ø} = 0\ \mu m$

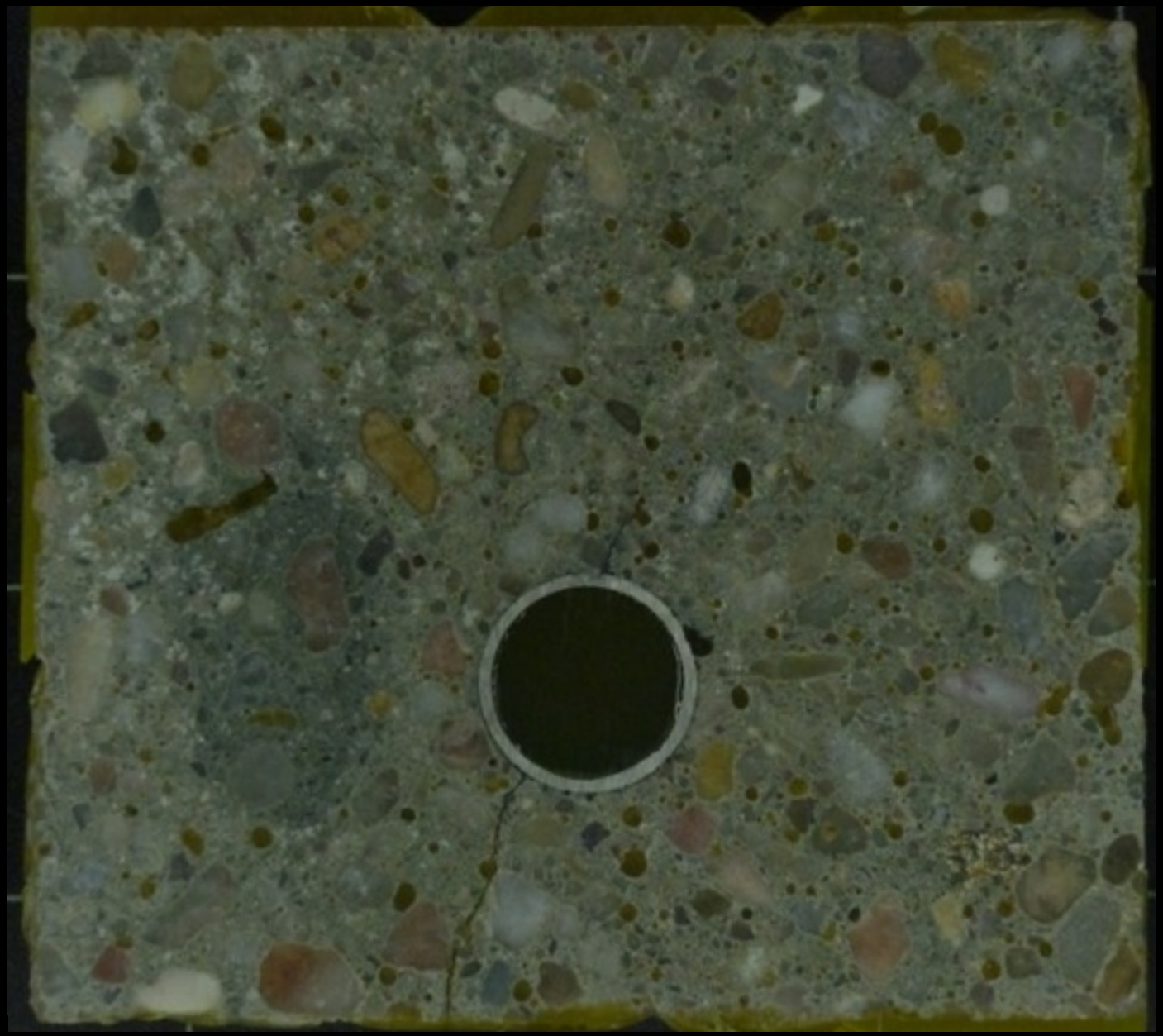


T03-05-R02

Crack pattern in accelerated corrosion tests

$\Delta\text{ø} = 40\ \mu m$

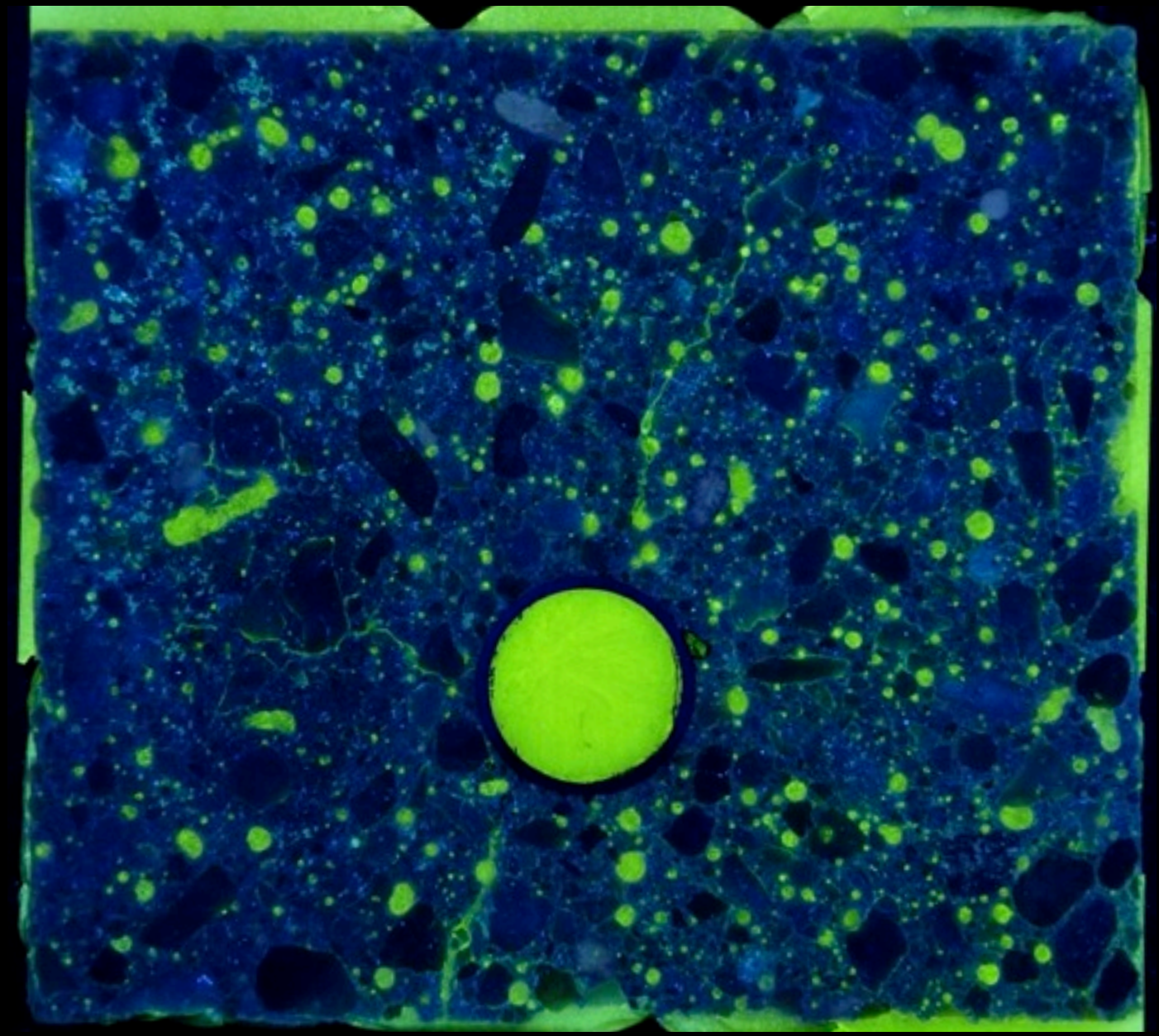
(Estimation: Andrade 97)



T03-01-R02

Crack pattern in accelerated corrosion tests

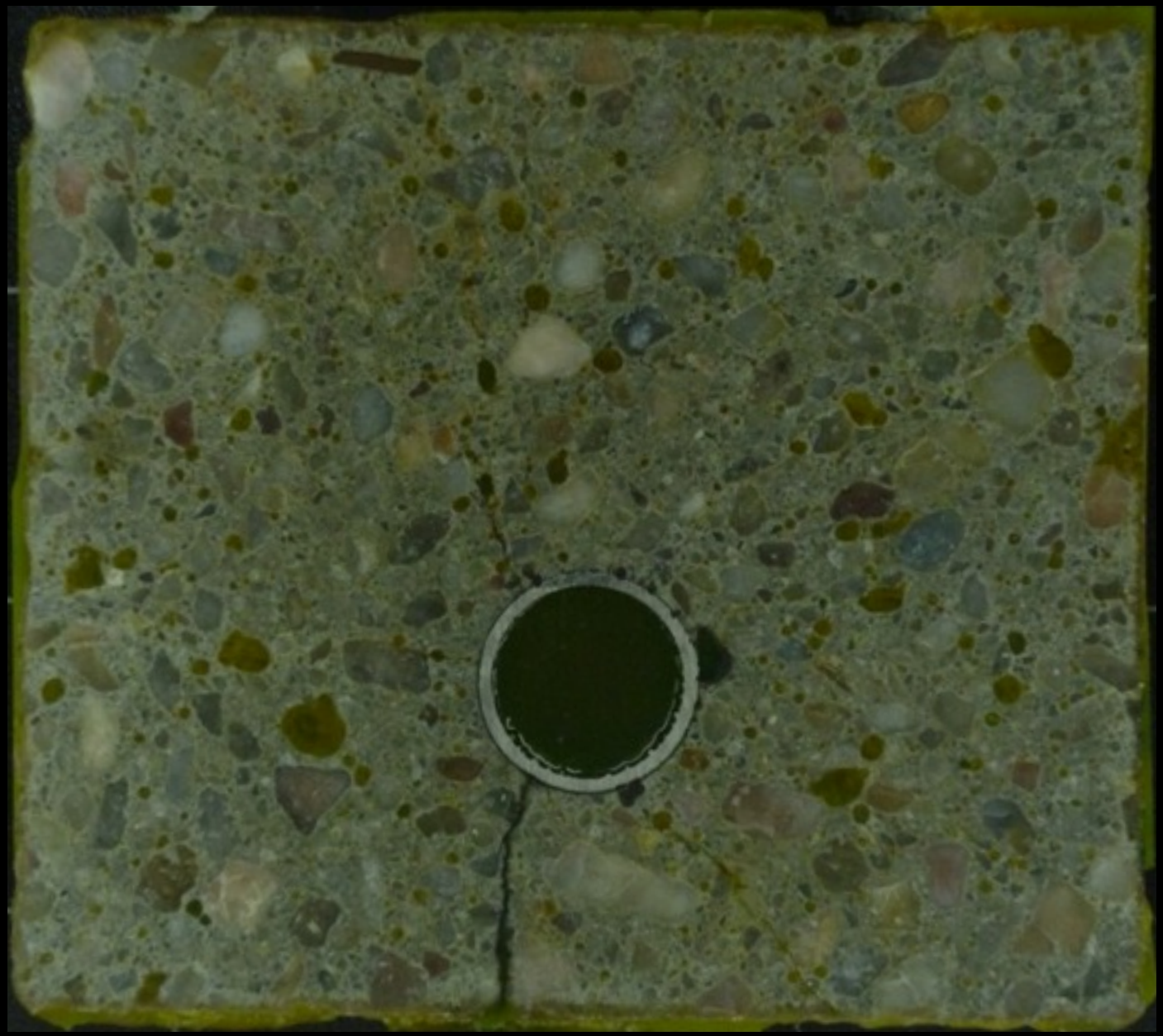
$\Delta\text{ø} = 40\ \mu m$



T03-01-R02

Crack pattern in accelerated corrosion tests

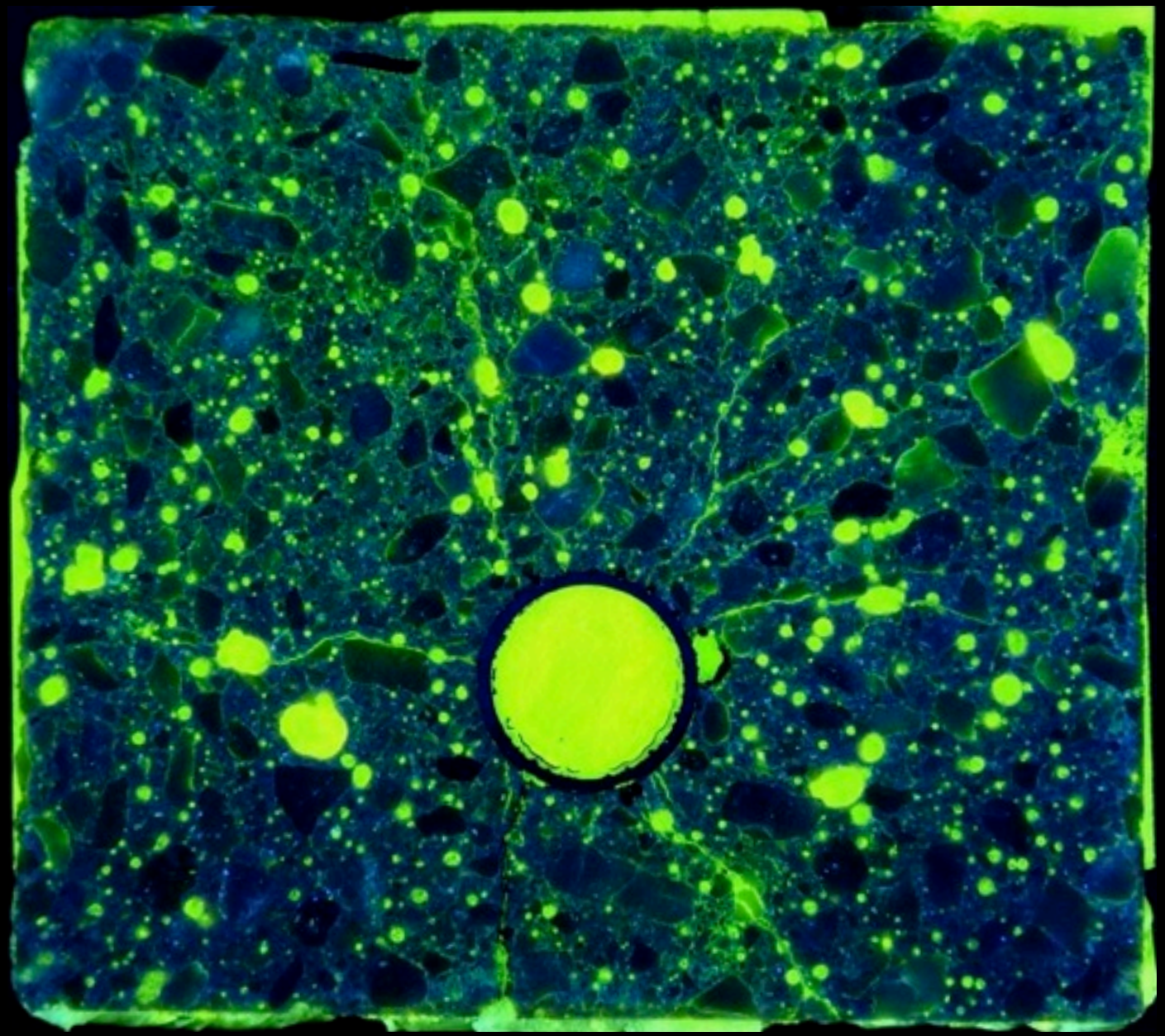
$\Delta\text{ø} = 200\ \mu m$



T03-04-R03

Crack pattern in accelerated corrosion tests

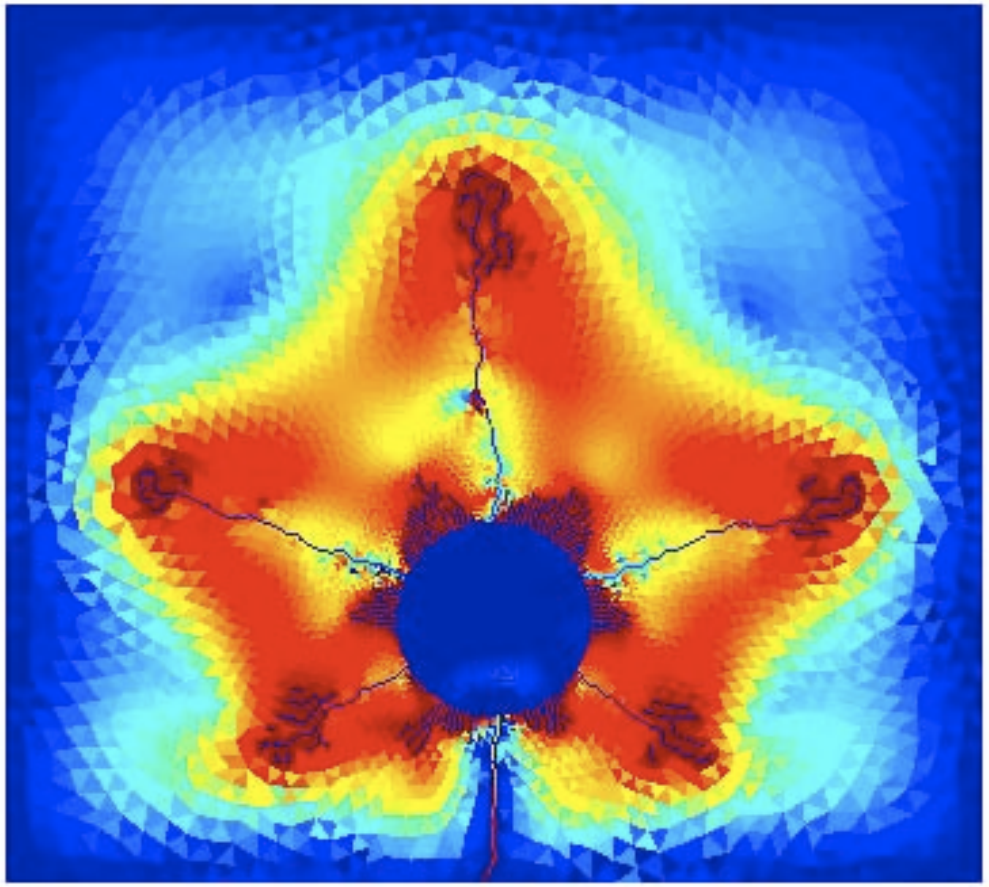
$\Delta\text{ø} = 200\ \mu m$



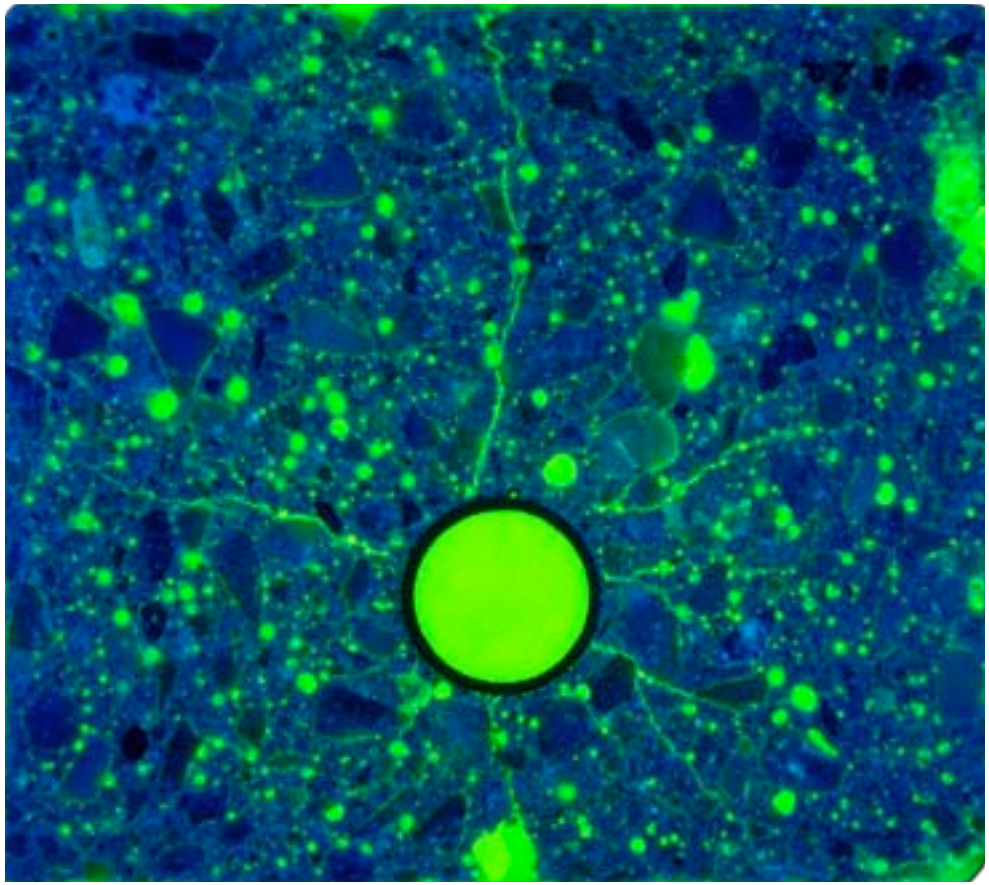
T03-04-R03

Comparison of the crack pattern

Simulations pattern



Experimental pattern



Summary

- A model called expansive joint element was programmed to simulate the oxide layer behaviour
- The numerical simulations with that model predict a wide main crack across the concrete cover but also some secondary cracks, in agreement with accelerated corrosion tests
- The impregnation under vaccuum of the samples with resin containing fluorescein improves the cracks detection
- The surface treating has been proved not to produce any cracks on the concrete surface
- The wider cracks contain less resin than the smaller ones. It can be due to the presence of compact oxide that does not let the resin come inside the cracks

Thank you for your attention